Power Quality implications of new residential appliances

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Abstract

Power Quality (or more accurately Voltage Quality) has become a significant issue in New Zealand with the changing nature of the loads. In the residential sector, many home appliances being bought now have electronic power converters which characteristically draw a non-sinusoidal current waveform. This results in increased harmonic levels in the distribution network. Unfortunately, some of these appliances are also relatively heavy loads, and many of the lighter loads have little harmonic diversity between them. An investigation is in progress by the EPECentre and University of Canterbury (funded by Foundation for Research, Science and Technology (FRST) and the EEA) to develop Power Quality guidelines. As part of this, characterisation of the harmonic emissions from home appliances being sold and used is required so that the possible effect on distribution networks can be determined. Moreover, this will point to possible mitigation options that can be implemented. This paper gives an overview of the home appliances tested so far, so as to provide some insight into how they will impact Power Quality levels in a distribution network.

1 Introduction

All equipment connected to the electrical network is designed to operate with a sinusoidal voltage at rated value. Power Quality (PQ), or more accurately Voltage Quality, is essential for electrical equipment to operate correctly. Power Quality is the degree to which the supply voltage waveform conforms to the ideal sinusoidal waveform (including magnitude and timing). Any deviation from this is a PQ issue [1].

In residential homes and small commercial operations, many appliances that are bought have electronic power converters which draw a non-linear current waveform, resulting in increased harmonic levels in the distribution network. Some of these appliances are also a significant heavy load. However, of importance is the harmonic diversity between appliances in the same category and also of other types of appliances. Lighter loads can still have a large impact on the network if harmonic currents from similar appliances have a similar phase.

New Zealand was one of the first countries to pass regulations (ECP36) in 1981 to limit the harmonic levels in the electrical network. While this was primarily due to the harmonics from the HVDC link, it is becoming relevant to general distribution networks. As harmonic levels rise each year, harmonic limits may be exceeded and they are eventually likely to impact on electrical equipment and appliances in the form of malfunctions or shortening of life.

2 Appliance characteristics

The rectification process by which AC is converted to DC is a common source of harmonics. This process is widely used in household appliances such as TVs, stereos, PCs, microwave ovens, compact fluorescent lamps (CFL), fluorescent lamps with electronic ballasts, LED lighting, and all types of chargers (for cell phones, cameras etc). The level of harmonic distortion is very much a function of the design of the rectifier. The problem is that market forces increase pressure to cut costs, which results in a poorer rectifier. This section provides a detailed overview of recent tests performed on new plasma TVs, LCD TVs, stereos, CFLs and heat-pumps, all of which typically operate for hours in the residential home.

2.1 Plasma TVs

Harmonic aspects of six plasma TVs were measured using a Chroma programmable AC source that provided a stiff voltage waveform. Waveforms and harmonics were measured using a Fluke 41B PQ analyser, as shown in Figure 1.

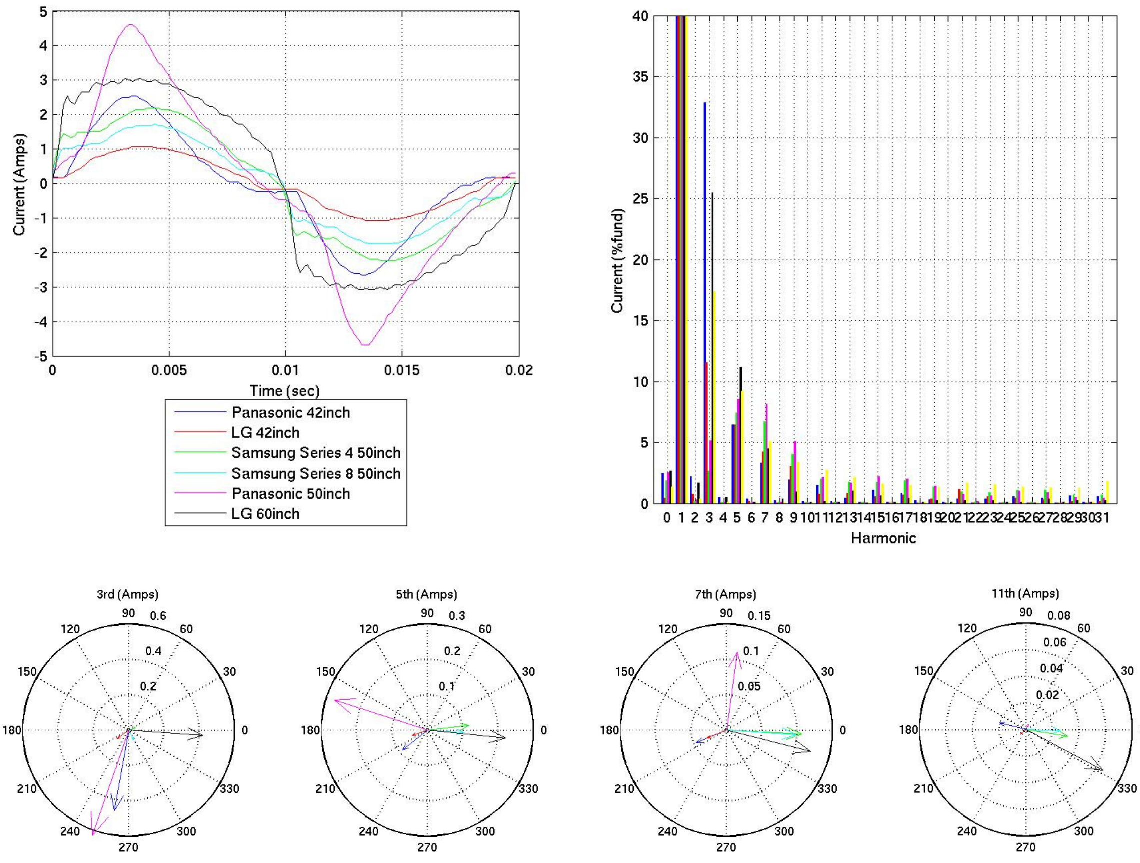

Figure 1 – Plasma TV current waveforms, harmonics and harmonic angles.

There is some significant variation in current waveforms of plasma TVs, and some correspondingly large variation in magnitudes at each harmonic. Harmonic angles show more diversity than other appliances, except for the 7th.

Figure 2 shows how the current THD varied with voltage source changes. There is a general upwards trend in current THD with voltage increase. This sort of trend is important where voltage drop occurs along a feeder. A clipped (4% of amplitude) voltage source is often seen today with the many power electronics devices drawing power only at the voltage peak. However, the current THD was equal to or lower than with the pure sine voltage source for most devices.

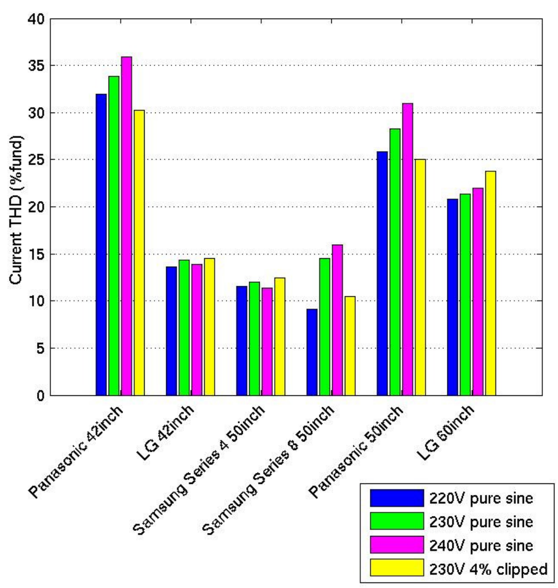

Figure 2 - Effects of voltage variation.

2.2 LCD TVs

Harmonic aspects of eight LCD TVs are shown in Figure 3.

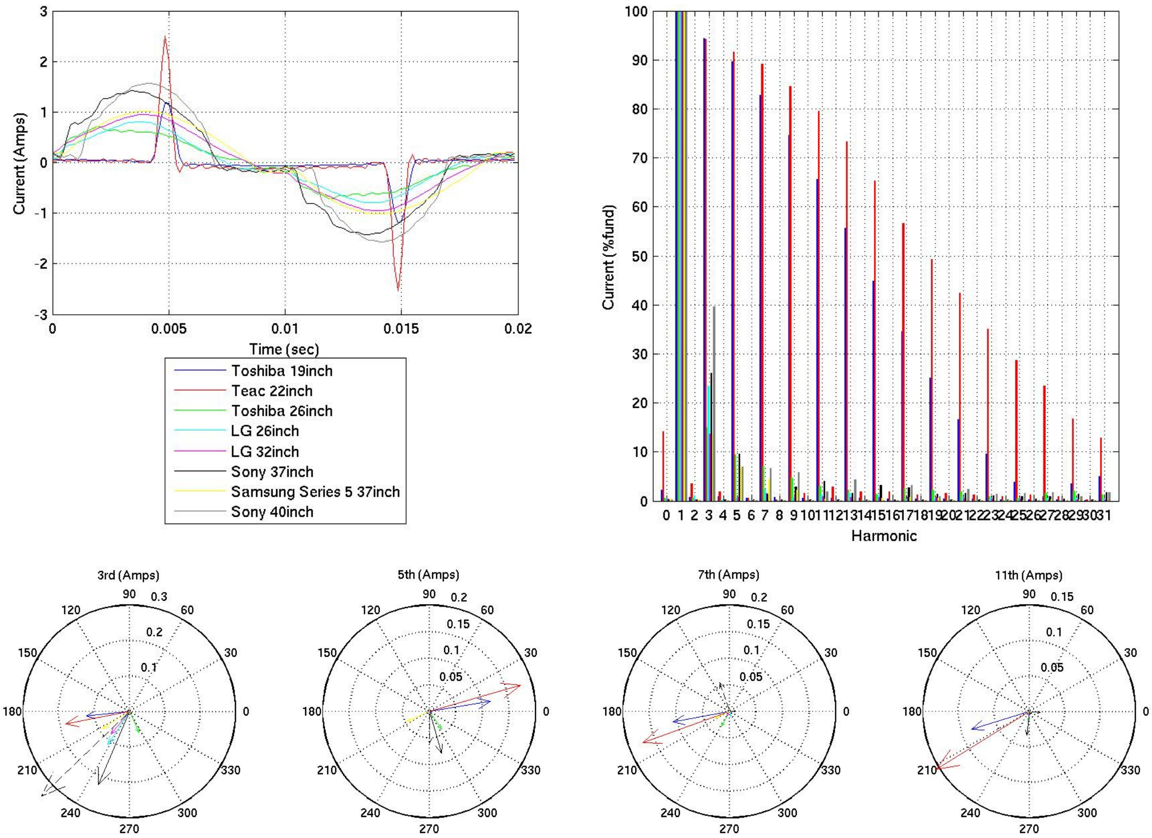

Figure 3 – LCD TV current waveforms, harmonics and harmonic angles.

The LCD TVs generally drew less (~20-40%) power than plasma TVs and were more consistent in power variation over time. The two smallest TVs were powered by an external AC adaptor, and have a significantly more peaky current waveshape, with correspondingly much larger higher order harmonics. However, diversity in harmonic angles is much lower for LCD TVs than plasma TVs for all of the above harmonics shown. This will result in harmonics generated from different LCD TVs reinforcing each other rather than cancelling, causing higher voltage distortions at Points of Common Coupling (PCC).

Figure 4, showing the variation in current THD with source voltage changes, presents the same upward trend with increased voltage.

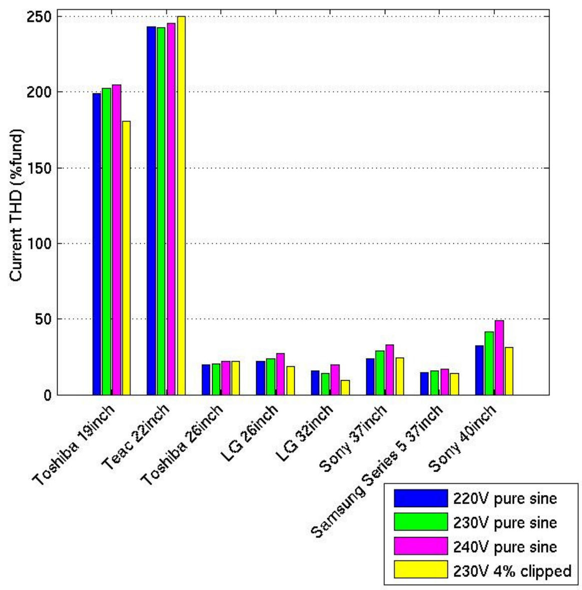

Figure 4 - Effects of voltage variation.

2.3 Stereos

Harmonic aspects of eight mini-system style stereos are shown in Figure 5.

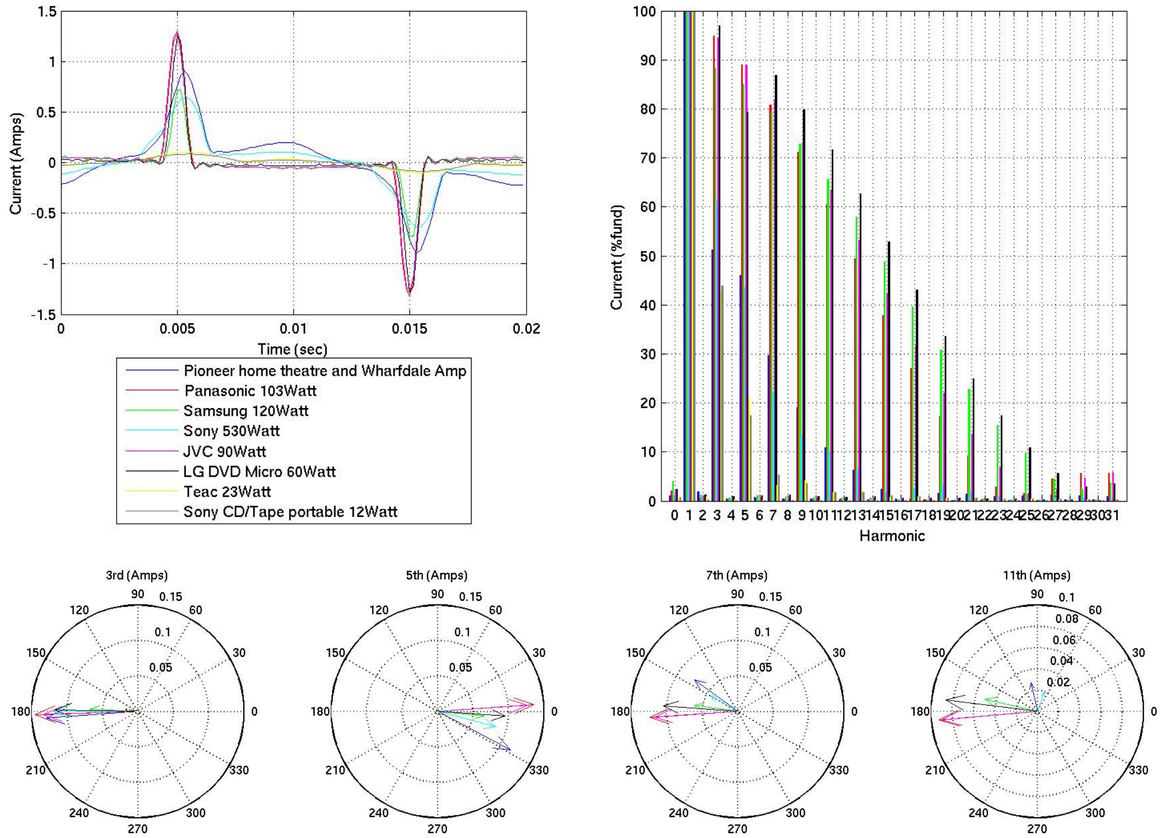

Figure 5 – Stereo current waveforms, harmonics and harmonic angles.

In contrast to the TVs, all of the measured current waveforms had a high crest factor, and this shows in the broad array of harmonics. The impact of these appliances is likely to be minimised due to the lower typical power draw (10-50 Watts). Unfortunately, there is little harmonic angle diversity, with the 3rd and 5th harmonic angles generally aligned with both plasma and LCD TVs. The 7th and 11th harmonics also align well with LCD TVs. While lower power appliances are of less general concern to the network, where many of these devices are operating, the harmonic angle alignment and therefore reinforcement may result in significant harmonic voltages on the network.

The flat section of a clipped voltage source is when stereos draw their current, often resulting in a lower RMS current and therefore THD, as shown in Figure 6.

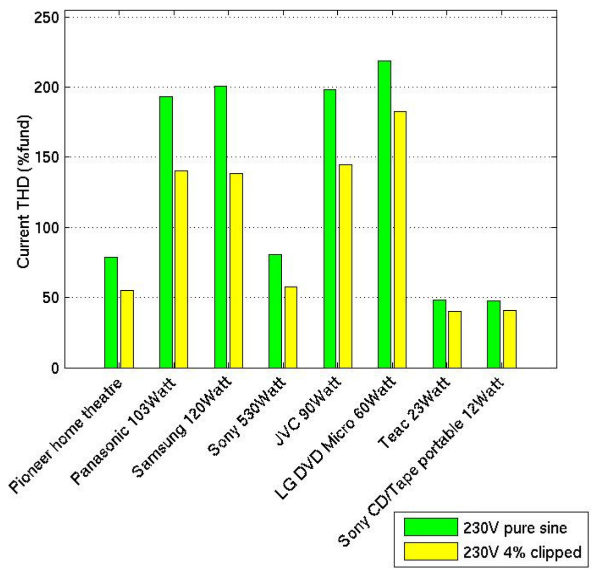

Figure 6 - Effects of voltage variation.

2.4 Heat-pumps

Harmonic aspects of six heat-pumps are shown in Figure 7.

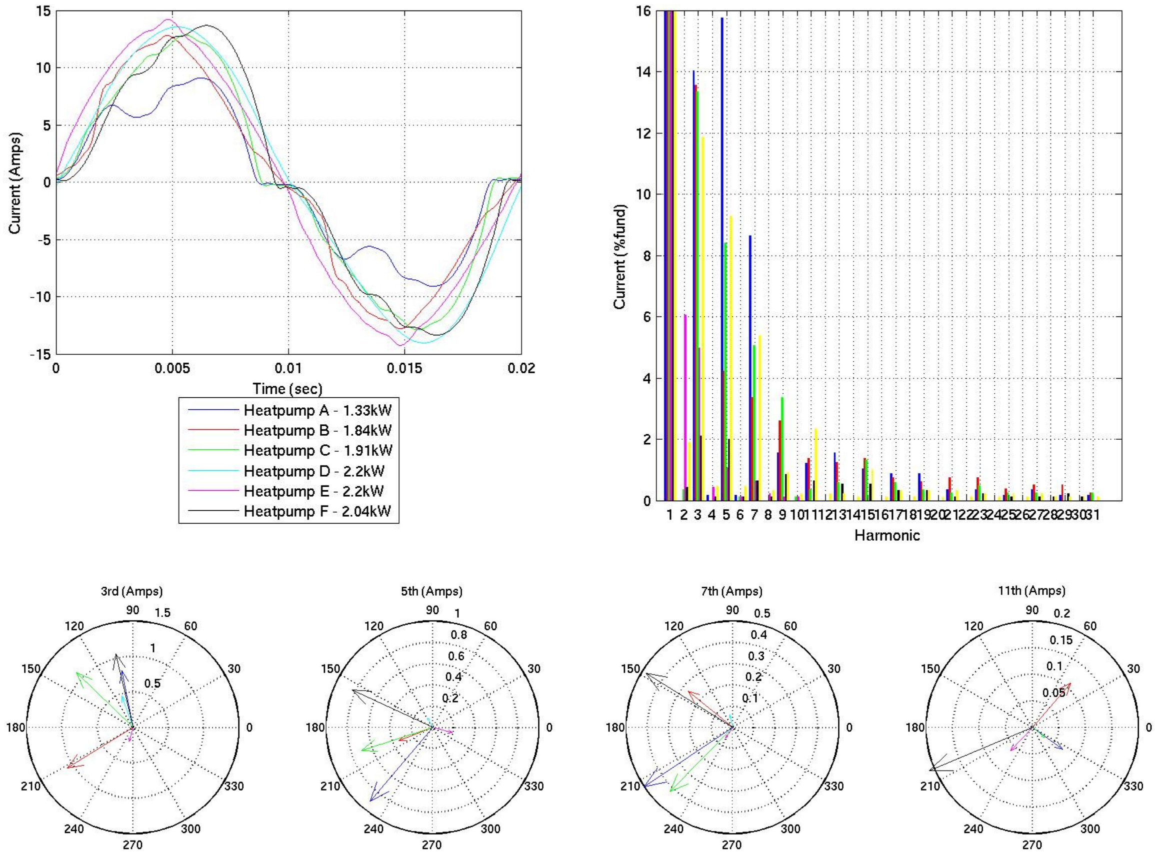

Figure 7 – Heat-pump current waveforms, harmonics and harmonic angles.

While early model heat-pumps often used directly connected induction motors, many modern heat-pumps use Variable Speed Drives (VSD) which increase efficiency but are known to be a source of harmonics [2]. The directly connected on-off Heat-pump D behaves as expected with a fairly smooth sinusoidal current. The heat-pump harmonics shown are at full rated power, but percentages increase significantly when operating at lower power levels. When the heat-pumps are in cooling mode, harmonic levels tend to be similar, but at lower power. Low diversity between heat-pumps exists for the 3rd, 5th and 7th harmonics.

As shown in Figure 8, current THD increases with increased source voltage, with indications that some heat-pumps operate as constant power devices.

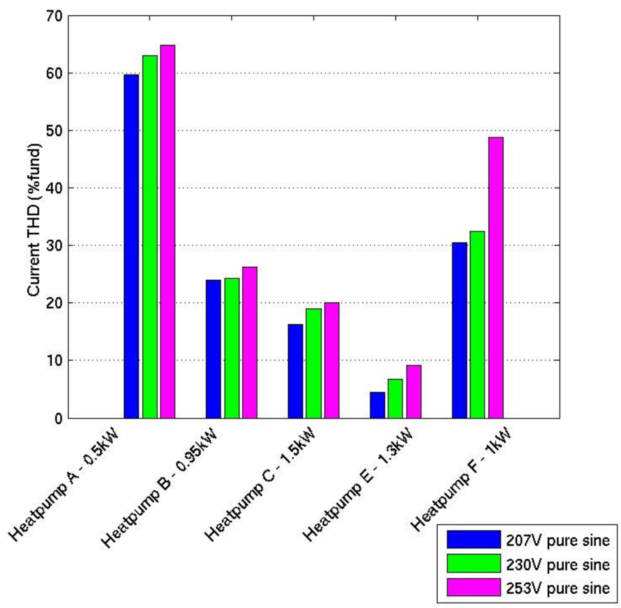

Figure 8 - Effects of voltage variation.

2.5 CFLs

Harmonic aspects of eight CFLs are shown in Figure 9. These bulbs have power ratings from 15-20 Watts, and are models that are often used in urban homes.

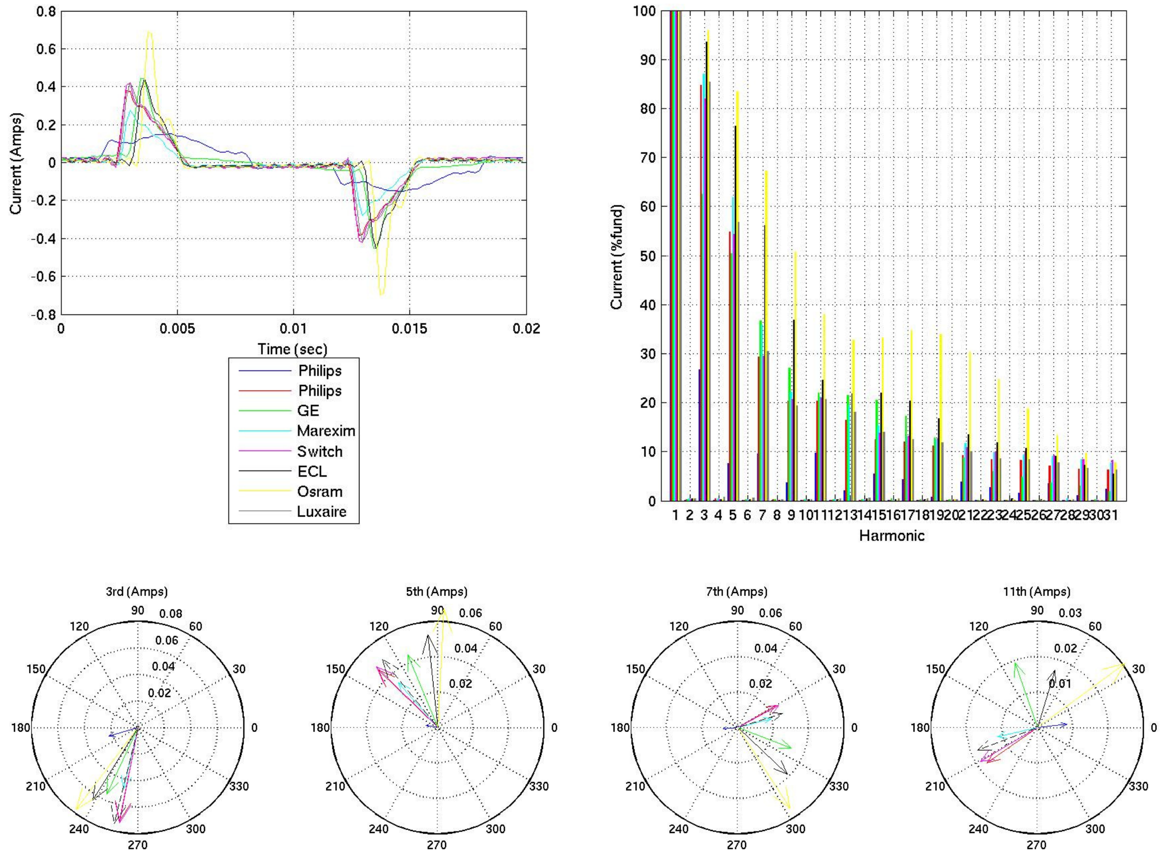

Figure 9 – CFL current waveforms, harmonics and harmonic angles.

Most of the CFLs shown have a high crest factor and quite similar waveshapes, indicating they share similar rectifier circuitry. As a result, a broad spectrum of harmonics is present that exceeds the 31st harmonic. Unfortunately, there is low harmonic angle diversity between the majority of CFL bulbs. While the low power of these bulbs means that the absolute magnitude of the harmonic currents of a single bulb will be relatively small, each residential home is likely to have several CFL bulbs switched on at the same time, unlike appliances such as plasma TVs. Home owners are also likely to purchase several bulbs of the same brand that will cause a harmonic situation with no diversity. Even if other brands are purchased, strong harmonic reinforcement is likely.

Typical circuit topologies presently used in CFL bulbs are shown in Figure 10. As shown by the valley-fill or active power factor control circuitry, significant improvements can be made by the addition of several components. Higher power CFLs (greater than 30W) often use the better filtering techniques, but sales of these devices are much lower. However, the cost of producing CFLs is relevant for mass production and so there is a strong incentive to minimise componentry.

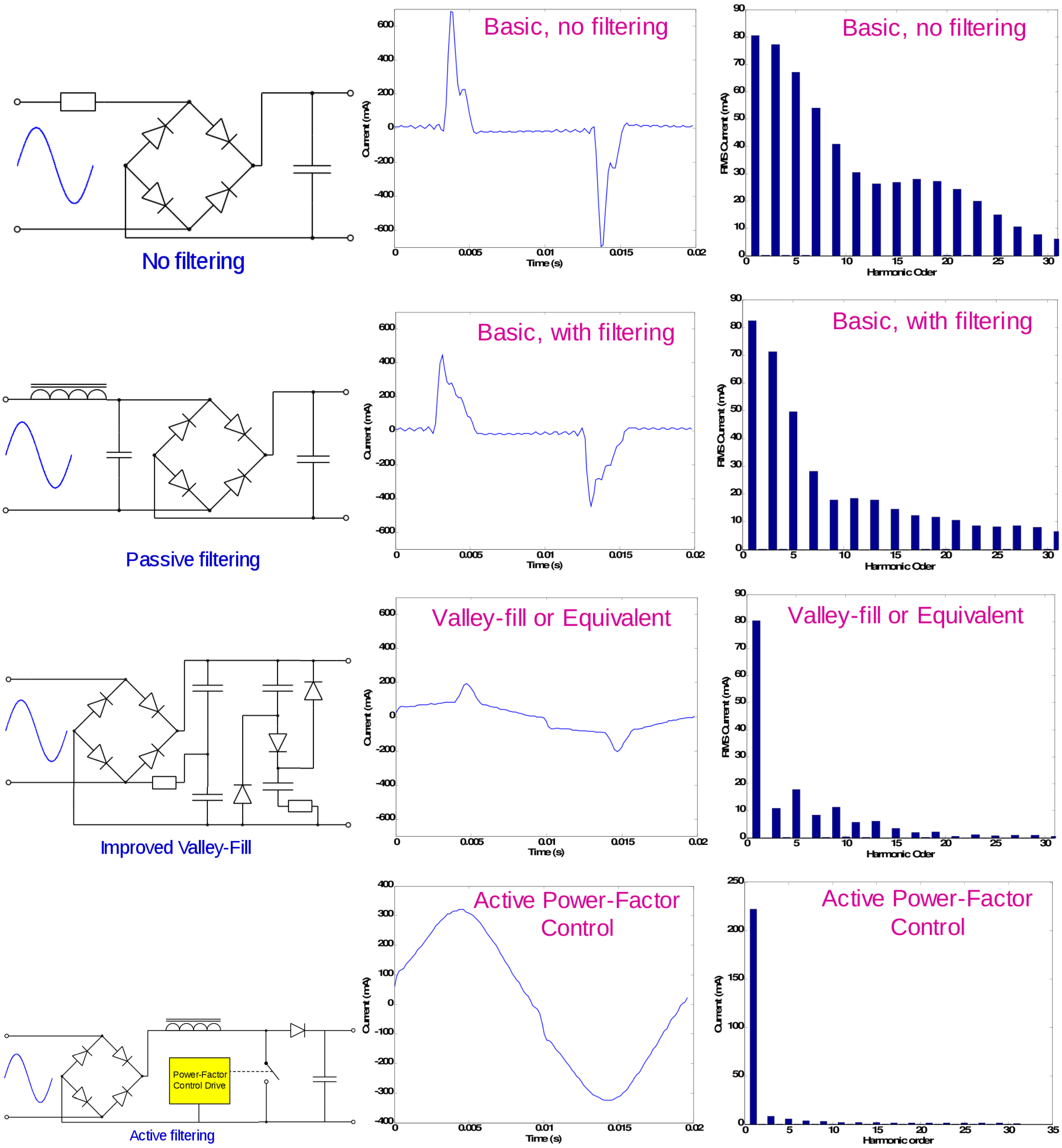

Figure 10 – Various CFL filtering options presently in use with their current waveforms and harmonics.

3 Appliance current THD comparison

The impact that current harmonics have on a network depends on the power of the appliance that is the source of the harmonics, and the current waveshape that appliance draws. Harmonic angle diversity is relevant when multiple appliances are operating simultaneously, creating either reinforcement or cancellation of harmonic magnitudes. Figure 11 shows a comparison of the appliances tested in this paper. Appliances with poorer harmonic performance tend towards the upper right of this figure. While CFLs and stereos have high current distortion, their low power and current magnitude limit their harmonic impact on the network. Heat-pumps have higher power, but lower current distortion. Of interest is the significance of multiple CFL bulbs, the presence of which is likely in most residential homes.

The effect of very low harmonic angle diversity is to consider that multiple CFL bulbs act as a single high power CFL bulb with relatively high current distortion. This may be of concern to the network.

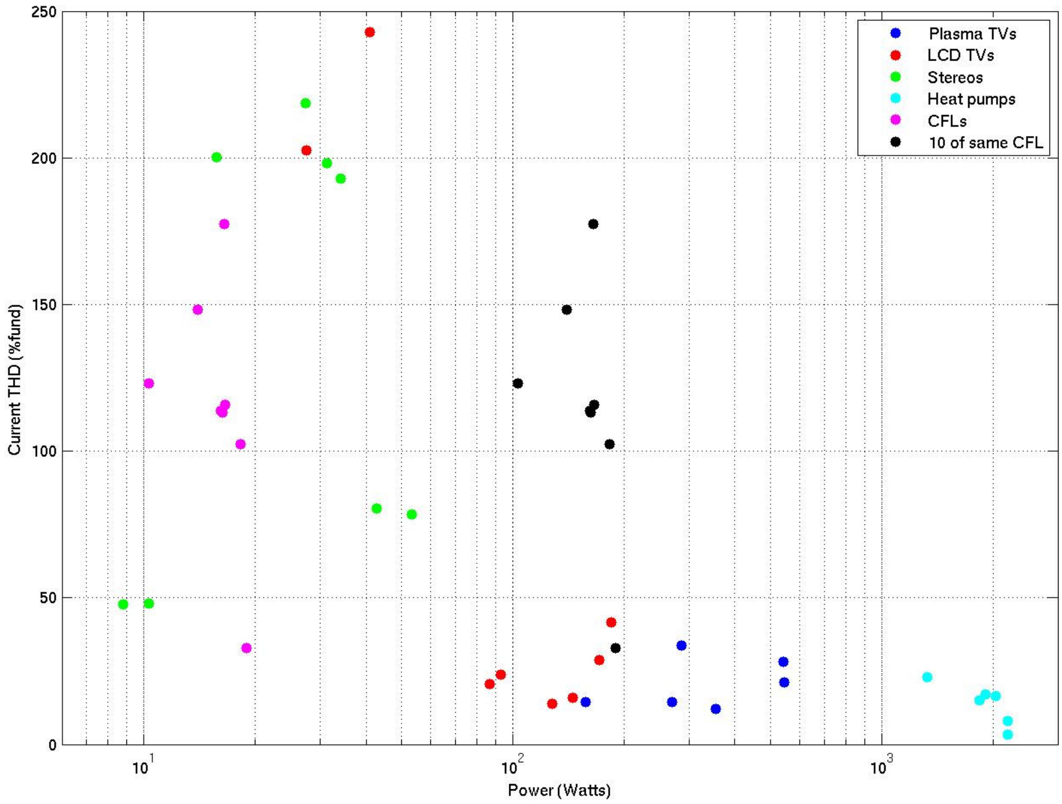

Figure 11 – Comparison of current distortion between categories of appliance.

4 Network feeder impact simulations

To determine the harmonic impact that the tested appliances have on a distribution network, an LV feeder computer model was built to which multiple tested appliances were modelled and connected. The modelled feeder, shown in Figure 12, is typical of New Zealand overhead line feeders and consists of typical length and electrical impedance parameters for such an urban feeder. Each of the 50 linear loads in the figure represents an urban dwelling. The 300kVA transformer is connected to a MV and HV network up to the Grid Exit Point (GXP). Harmonic voltage distortion measurements were calculated at the transformer terminals (top of feeder) and the end of one of the feeder lines (bottom of feeder). This is shown as nodes A and B in Figure 12.

Several scenarios were calculated where 40 appliances in each category of appliance tested in this paper were connected at random locations around the feeder. Approximately equal numbers of each model of appliance within the category were used. For instance, the first scenario had 6 or 7 of each type of plasma TV (total 40) connected to the already present linear loads, scattered in random fashion across houses and phases. Scenarios were also calculated for where 10 CFL bulbs were connected per house (total 400), and where all appliances (including 10 CFLs per house) were connected. To keep the total feeder load approximately level in the various scenarios, the individual linear loads were set to 2.5kW for

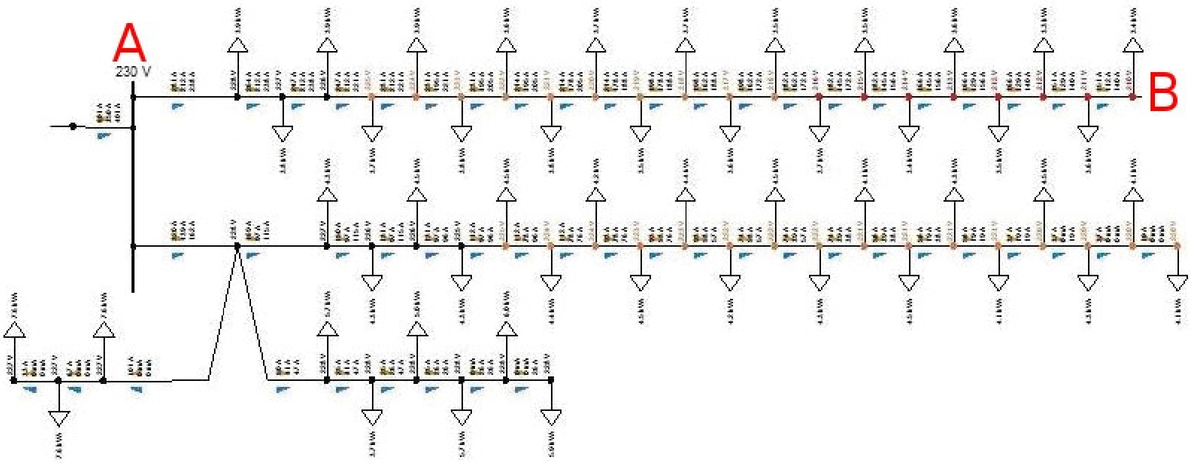

Figure 12 – Model of LV feeder consisting of overhead lines where each load represents a single urban dwelling.

the first five scenarios, 1.5kW for the heat-pump scenario and 1kW for the scenario where all appliances were connected. Additionally for each scenario, calculations were made for modelled appliances with their measured harmonic angles and for where all appliances had no diversity, that is, all harmonic angles were set to zero. This reveals the reduction in harmonic voltage that multiple appliances will provide due to harmonic currents being partially out of phase resulting in their partial cancellation.

Calculated harmonic voltage increases at the top and bottom of the feeder are shown in Figures 13 and 14. The most significant, single appliance category harmonic voltage increases are due to multiple CFLs and to heat-pumps. This shows that CFL bulbs are likely to be one of the highest sources of harmonics on present distribution networks, especially as many heat-pumps are unlikely to be all running simultaneously for long periods, while multiple CFL bulbs are often switched on for hours in the evenings. However, the effect of all appliances being simultaneously connected is to provide some more harmonic angle diversity between the categories of appliances and thus a much lower harmonic voltage is generated than what the scalar sum of the harmonic currents of all the appliances would create. For instance, the harmonic angle diversity of all appliances lowers the voltage THD from a possible 3.2% to an actual 1.2%, as shown in Figure 13.

In general, harmonic voltage levels at the end of the feeder were up to 50% larger. The effects of harmonic angle diversity were also reduced. This would be of concern for longer feeders. Measurements made by PQ equipment at the PCC or transformer terminals may not be indicative of the harmonic levels further down the feeder.

Other types of LV feeders will vary the effects of harmonic voltages. For instance, underground cable feeders, in a high density residential area, are likely to experience harmonic voltages 10-30% lower. Harmonic voltage increases are likely in longer feeders in rural areas due to the higher line impedances.

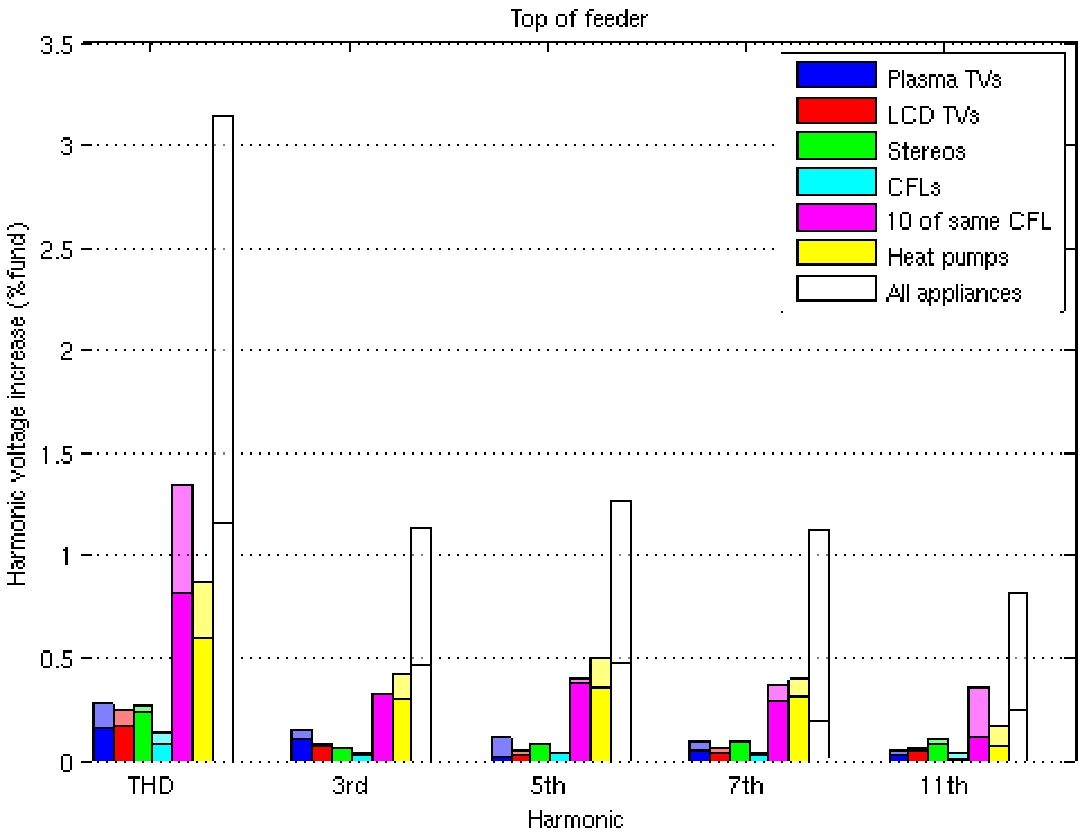

Figure 13 – Harmonic voltage increases at the top of the feeder (node A) for various appliance connections. No harmonic angle diversity scenarios are represented by the lighter coloured sections at the top of each bar.

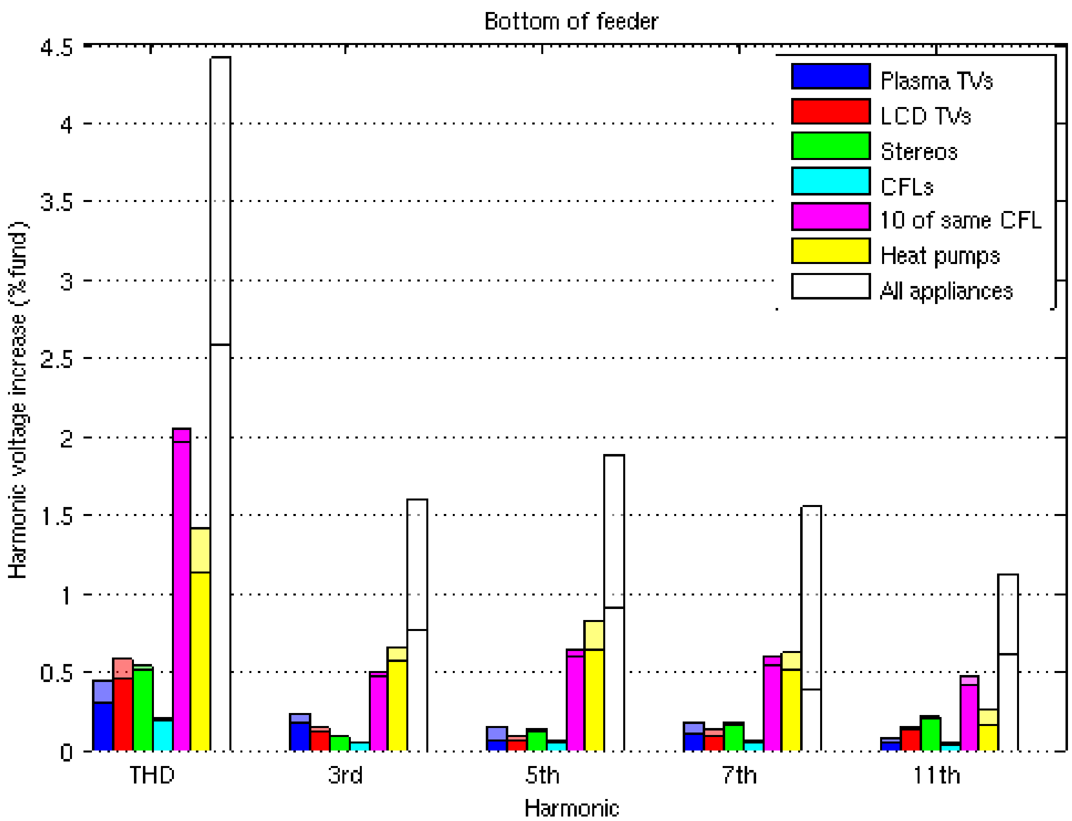

Figure 14 – Harmonic voltage increases at the bottom of the feeder (node B) for various appliance connections. No harmonic angle diversity scenarios are represented by the lighter coloured sections at the top of each bar.

5 Conclusions

The range of appliances tested and measured shows that many of the loads being connected to the network today create moderately significant current harmonics. While the power of most of these devices is low, the large and increasing numbers of appliances with low harmonic angle diversity means that harmonic voltage levels are likely to rise in the future within LV and MV distribution networks. New non-linear appliances are now being sold which will replace present linear loads. For example, resistive water cylinder heaters may be swapped for water heat-pumps and domestic fridge/freezers are now being sold that use a VSD, as shown in Figure 15, instead of a compressor. These new appliances are likely to accentuate the harmonic issues.

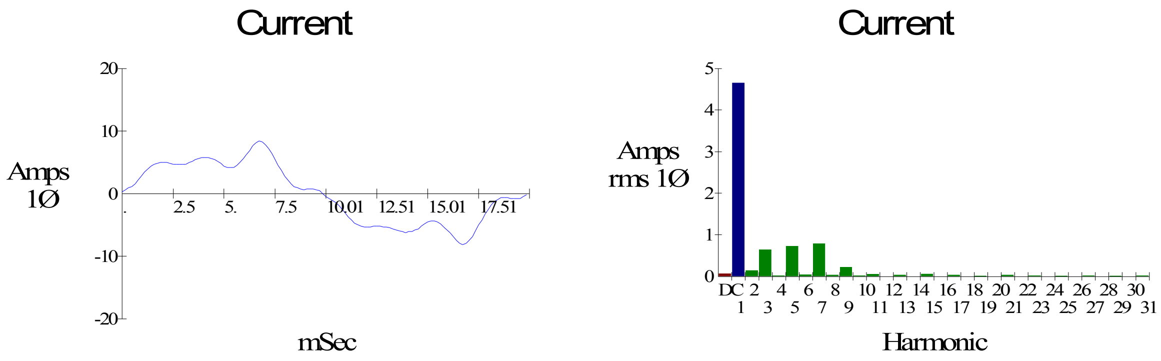

Figure 15 – Current waveform and harmonics (current THD fund = 27.5%) of a new Leibherr domestic fridge/freezer appliance that uses a VSD.

References

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[2] Heat Pump Power Quality: Harmonics and Power Factor, Bill Heffernan, Geoffrey Love and Nalin Pahalawaththa, EPECentre Conference on Power Quality, Christchurch, New Zealand, 23-24 April 2009.